

Educating structural engineering students to be creative designers

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INTRODUCTION

According to Mike Schlaich, professor in the Department of Conceptual and Structural Design at Technische Universität in Berlin, special attention is needed in engineering education to develop students' skills for designing structural concepts [1]. Even though conceptual design is often underexposed in engineering education, it is essential for creative or innovative design. (Here creative or innovative design stands in opposition to routine design in which a predetermined design procedure will lead to a solution [2]). Schlaich states that most engineering programs focus on developing the skills to calculate and dimension structures, but not on conceiving structural designs on a conceptual level. Structural engineer Laurent Ney also identifies this lack of conceptual design skills in structural engineers. In his view, engineers today are well equipped to dimension structures, but not to conceptualize them [3].

In order to design structural concepts an adapted language is not only required to express, but also to create such concepts. Here language is not only a tool to communicate meaning, but it also affects the construction of our system of thoughts in which this meaning is understood. Within the cognitive linguistics it is shown that a language will influence how we perceive and understand phenomena. Lera Boroditsky states 'that people who speak different languages do indeed think differently and that even flukes of grammar can profoundly affect how we see the world' [4]. And thus in regard to structural design, language is an essential element in providing the building blocks to design structural concepts.

Within the doctoral work of the author [5] a proposal is developed for a new language to communicate and develop structural concepts. Focus of this doctoral research has been on a creative design collaboration between architect and structural engineer starting early in the design process (i.e. when design is still conceptual). This paper will introduce this language, show different results of its use in architectural education and describe its qualities for use in structural engineering education.

1 A NEW LANGUAGE FOR DESIGNING STRUCTURAL CONCEPTS

Structural design propositions described with currently available engineering languages are in general closely related to calculation methods which only require a few additional design decisions to come to a design solution. 'In general, engineers tend to categorise structures according to which mathematical model and technique of structural analysis they might use, ...' [6]. This leads to building blocks for a design creation of various structural typologies like beam, column, slab, tie, Vierendeel-girder, truss-girder, dome shell and peak tent. Each of these typologies possesses distinctive characteristics of structural analysis and are accompanied by methods of dimension calculations. These structural building blocks of design contain already many design decisions and hinder a more conceptual design creation of structures that provides for an exploration of a wider range of possible design solutions.

Therefore a new language is developed through participatory action research in various cases of the author's professional and academic practice. This language is away from commonly used structural typologies and their calculation methods, and is to be understood as an addition to currently available structural languages. It enables to express essential characteristics of a structural concept like the chosen load paths, the composing elements of the structural system and the main structural functions each has to perform. This language expresses important structural design decisions that are made early in the design process.

1.1 A language of four layers

The proposed structural language aims to express structural logic as an important characteristic of a structural concept. Therefore it provides for an abstract representation with symbols that find meaning in four different layers: (1) structural order, (2) structural function, (3) structural dimensions and (4) structural design possibilities.

(1) Structural order reveals the structural relations between different structural elements for a specific load case: it shows which element is supported by which other element(s). It brings to the fore the path(s) a load follows throughout the system of structural elements to its supports (*Fig. 1*).

The layer of (2) structural function expresses the type of load transfer that occurs in a structural element: axial or parallel transfer of force, or axial or parallel transfer of moment. Each structural element is required to perform its structural function(s) to enable the structural system to bring the load to the supports.

The consequences of performing a structural function on the structural form of an element are expressed in the layer of (3) structural dimensions. This leads to five major types of structural dimensions: one for each type of structural function except axial transfer of force which is split into tension and compression (since buckling needs to be additionally considered for dimensioning in the latter case). This means that expressing the characteristics of structural dimensions also reveals the underlying characteristics of structural functions that each element needs to perform (*Fig. 2*).

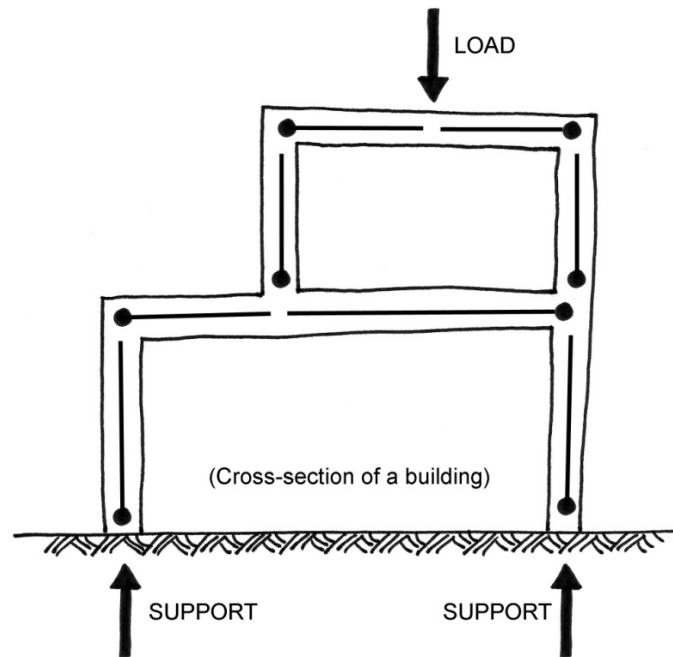


Fig. 1. Structural order: identification of structural axis (-) and load paths (•)

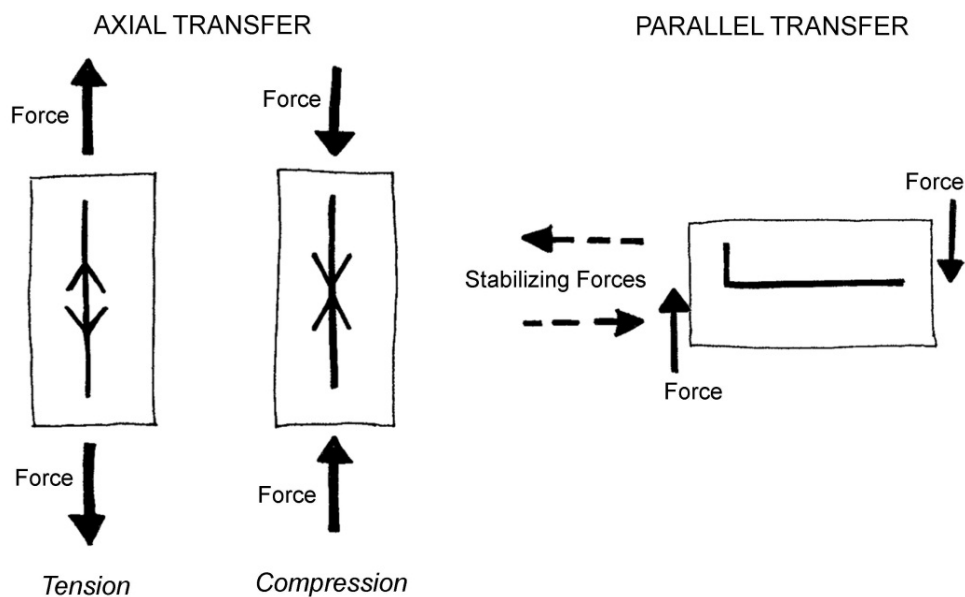


Fig. 2. Structural dimensions layer: symbols for transfer of force.

The layer of (4) structural design possibilities links each element and its characteristics of structural dimensions with a wide range of possible (built) structural design solutions. These solutions as material form bring the conceptual design into the realm of built reality of structures (Fig. 3).

The proposed language consists of symbols that express characteristics of the layers structural order and dimensions, and is accompanied with a catalogue of (built) structural design solutions organized according to their characteristic of structural dimension and architectural expression of conceptual form (e.g. rectangle surface).

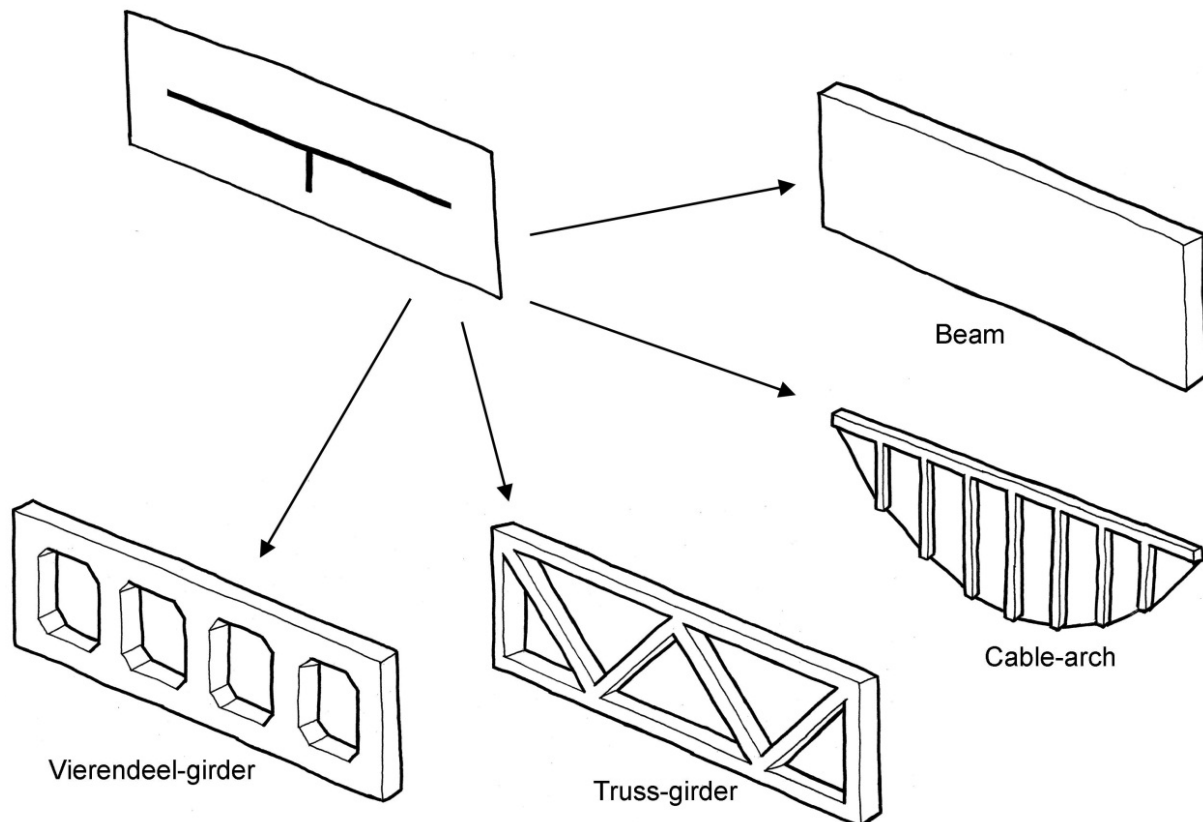


Fig. 3. Structural design possibilities for a rectangle surface that divides load.

1.2 Language application

This language is initially developed as a communication tool for a structurally informed architectural design during a collaboration of architect and structural engineer. Here, the proposed language of symbols can be applied to an architectural form model by providing each conceptual element with structural information about its structural order and dimensions. This can lead to rich three-dimensional drawings that on the one hand express the structural behaviour of a system of conceptual elements, and on the other hand create spatial experiences that relate directly to architectural design. Such drawings articulate conceptual design decisions for negotiation (*Fig. 4*) and provide a common ground for communication during design collaboration between architect and structural engineer.

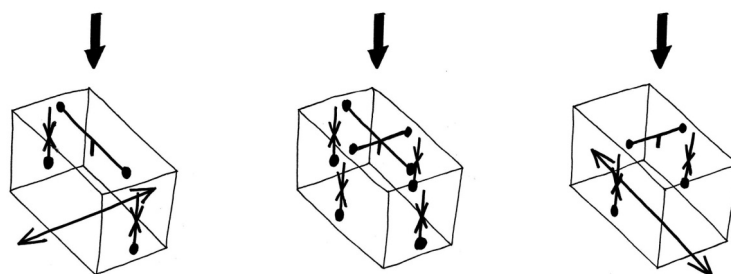


Fig. 4. Articulation of conceptual design decisions: choice of structural elements, their functions and connection, load path and supports.

1.3 Qualities of the proposed language

In the proposed language various qualities can be identified:

- *communicate structural logic*: drawings express the characteristics of the layers structural order and structural dimensions.
- *articulate conceptual design decisions* for negotiation between architect and engineer, but also for evaluation within the own design process of the engineer (cf. Lawson's 'proposition drawing' [7]): drawings mainly identify the chosen structural elements, loads, supports, load paths, required function(s) of each structural element and the type of element connection.
- *provide for more abstract building blocks of design creation* than current commonly used structural typologies of for example beams, columns, trusses and slabs.
- *provide for structural prototypes* (i.e. fully formed but profoundly abstract answer to a design question (Fig. 5)).
- *enable a delay decision strategy*: drawings express the structural logic of a design proposition without the need for more detailed information of structural typologies, material or dimensions. This enables a more conceptual in breadth-first search for design solutions by delaying design decisions about material and form.
- *filter structural information for the architect*: the amount of engineering-specific knowledge required to understand the structural logic is reduced, and information is focussed on decisive characteristics of structural form which directly relates to architectural design qualities.
- *easily and quickly drawn, and intuitively understandable*.
- *organize structural knowledge through a process of design refinement*: the language starts from conceptual principles and leads to detailed design solutions.

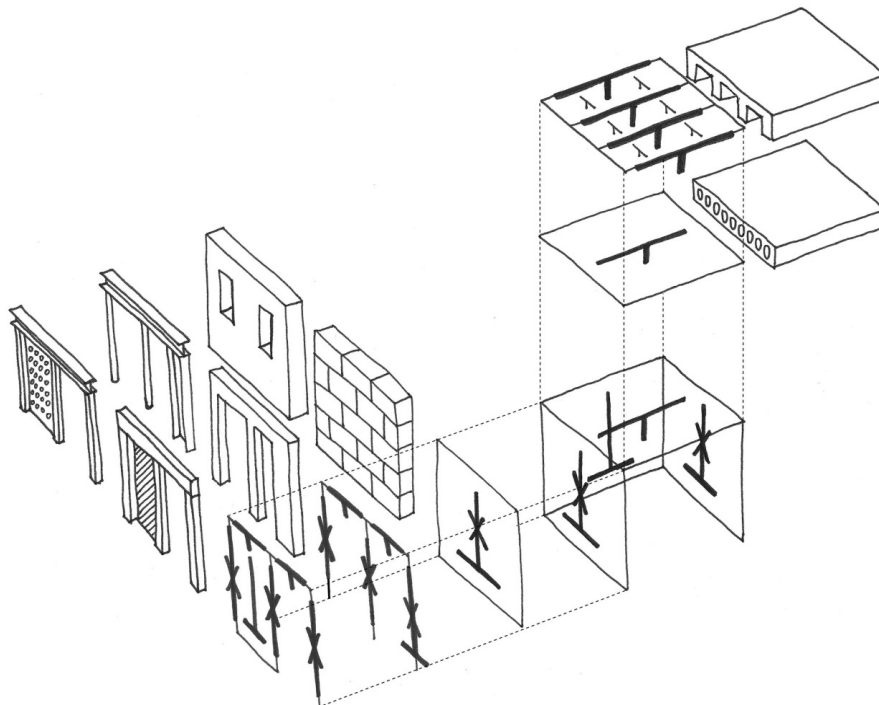


Fig. 5. Example of structural prototype: from prototype to a range of possible design solutions.

2 FOR ARCHITECTURAL EDUCATION

2.1 Application in structural theory courses

The proposed language can be applied in architectural education on various levels. It is developed for architects and architecture students to be easily learned, read and applied, and it is based on a designerly approach of structural knowledge going from concept to detail. This enables architecture students to easily relate to a structural understanding through the use of this language as tests have shown.

In these tests around hundred architecture students were asked to explain a structural behaviour with their own chosen structural language, which was mostly based on traditional engineering languages. Then after a short introduction into the newly developed language, they were asked to express the same behaviour with this new language. Next, the students' opinions on this new language was gathered through extensive questionnaires. It showed that most students found the language (1) easy to learn and use, and that it could (2) explain well the essence of structural behaviour as they comprehended it, even (3) with less images than with their usual language.

When students were then asked to explore in breadth for new structural designs through the use of this language, questionnaires revealed that about half of the students felt that (4) their general structural knowledge was increased by the use of this language, and that if other people understood these symbols, 75% of the students would (5) prefer using these symbols above the traditional internal forces diagrams to explain a structure. Most students (6) appreciated not having to go into designing details and being able to work only with a more abstract conceptual structure which this language enables. And some students expressed to (7) have found new structural design ideas at some point explicitly through the use of this new language.

These test indicate that applying this language in theory courses of structural education enables to (quickly) explain the essence of structural behaviour of various designs and to provide a designerly approach to structural knowledge to which architecture students then can easily relate. The author's experience of applying this language in his theory courses confirms this.

2.2 Application in design studios

As this language was specifically developed for a design collaboration between architect and structural engineer, it is a useful tool during structural consult in architectural design studio's, especially in the conceptual phase of the design process.

In order to investigate the use of this language as a communication and design tool in a design collaboration, a design studio was staged with seven architecture students with the author as structural advisor for their various architecture projects. Several face-to-face meetings between student and the author were set, starting early in the design process, and involved a communication of structural information through the use of the developed language. After handing in their design projects, students were questioned about the face-to-face meetings and the use of the language. The following conclusions could be made:

- *Students describe the structural language used in the face-to-face meetings as clear, direct, pure, intuitive, understandable and quick: you can learn it by using it, it does not need much explanation.*

- *Students state that the language is useful for the first phase of the design process, when there is a need for more abstract structural ideas, but that something ‘more’ is needed later on in the design process, when there is a need for more detailed information that this language does not provide.*
- *The language provides structural information on the level of an architect’s design culture.*
- *Students value the visual communication (with the language) more than a spoken one.*
- *Students say they use the language in their mind without putting it on paper, and that through the use of simple wire-frame models for the structural form models they are able to manipulate the conceptual design in their mind.*
- *Students look forward to using a catalogue that links the conceptual design (expressed in the language) with the variety of possible built reality for their architectural design process.*
- *Students would like to see this language applied in and linked with present theory courses.*

In addition, based upon his notes and the produced project results of the students, the author concludes that (1) the language enables him to quickly and easily write down the structural story of a conceptual design proposal, with the advantage to be (2) still consultable by students after the meeting is over. (3) The students are able to grasp the expressed structural behaviour of the structural proposal and even to further the structurally design if necessary. The evolution and results of the different design processes also make apparent that (4) the architectural design process is guided by the given structural information.

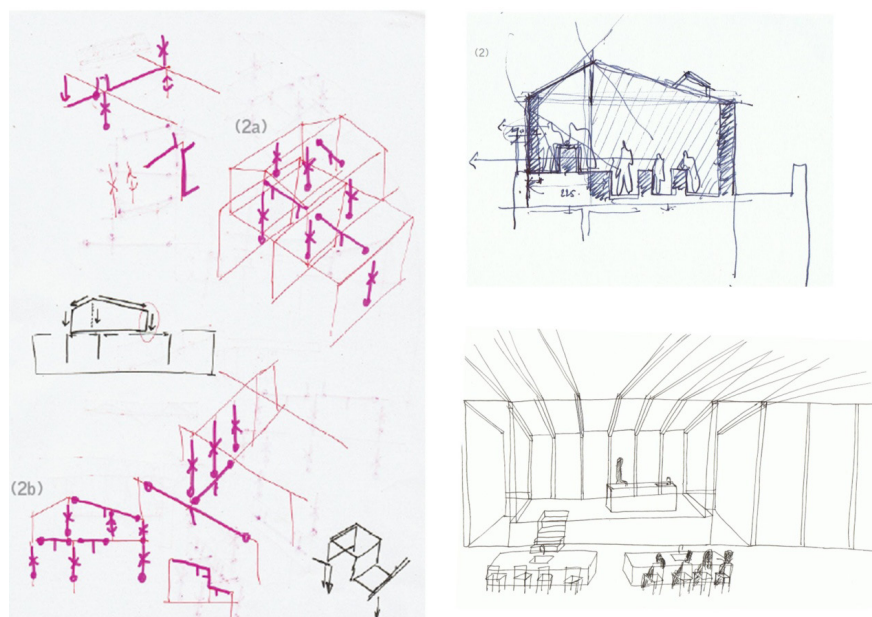


Fig. 6. Example of a student’s design project: conceptual structural design sketch and architectural proposition before (top) and after (bottom) structural consult.

3 FOR STRUCTURAL ENGINEERING EDUCATION

Based on results of the application in architectural education and the personal experience of the author in using this language during structural designing, possible benefit is to be expected in engineering education from the use of this language and its underlying structural knowledge approach.

In structural theory courses this language can provide for a more holistic, conceptual approach to a structural understanding, as application in architectural education has shown already.

But moreover this language is an interesting tool to develop skills in designing structural concepts for several reasons:

- *little engineering-specific knowledge is needed* to master the use of the language: this means that it can be used already early on in an engineering education program to develop a structural understanding.
- *the language enables to create 'proposition drawings' [7] of conceptual structural designs*, in order for the designer to stand back and 'have a conversation' with the own developed conceptual design.
- *the language enables to provide rich three-dimensional drawings of structural systems*. This facilitates a three-dimensional investigation of structural design in which the third dimension might reveal more creative design possibilities than would an investigation relying on two-dimensional drawings.
- *the language supports a search in breadth-first for structural concepts* without having to go into details or calculations, enabling to explore a wide range of possible design solutions.

Application of this newly developed language in engineering education still needs to be established for evaluation. The author sees much potential in this application, not only to train engineering students in designing skills, but also to educate them in a mutual language with architects for a creative design collaboration.

REFERENCES

- [1] Schlaich, M., (2007), Challenges in education - conceptual and structural design, *labse Reports*, Vol. 92, pp. 22–29.
- [2] Achten, H.H., (2008), Design processes: between academic and practice views, in W. Poelman & D. Keyson eds., *Design Processes: What Architects & Industrial Designers can teach each other about managing the design Process*, IOS Press, Amsterdam, pp. 14–27.
- [3] Strauven, I. and Ney L., (2005), Ney & Partners Freedom of form finding, Brunetta V. and Patteeuw V. eds., *Vlaams Architectuurinstituut*, Antwerpen.
- [4] Boroditsky, L., (2009), How does our language shape the way we think?, *Edge*, Available at: http://www.edge.org/3rd_culture/boroditsky09/boroditsky09_index.html [Accessed September 23, 2011].
- [5] Luyten, L., (2012), Structurally Informed Architectural Design, Proposals for a Creative Collaboration between Architect and Structural Engineer, Ph. D., Chalmers University, Göteborg.
- [6] Addis, B., (1994), *The Art of the Structural Engineer*, Artemis, London.
- [7] Lawson, B., (2005). *How designers think: the design process demystified*, 4th ed., Architectural Press, Oxford, pp. 45-49.